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Quantum Hash Descriptor for Planetary Motion in the Universe

A Deterministic Framework for Multi-Scale Astronomical Kinematics and Informational Identity

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Abstract

We present a deterministic quantum-inspired informational descriptor for astronomical motion across universal scales. The Quantum Hash Descriptor (QHD) extends the Quantum Hash Framework (QHF) to encode the physical, kinematic, entropic, energetic, temporal, and causal state of any celestial object into a reproducible continuous descriptor and a cryptographically stable discrete hash. While the Solar System is used as an illustrative example, the framework is designed for universal applicability, including stars, exoplanets, galaxies, black holes, nebulae, and large-scale cosmic structures. The QHD enables reproducible tracking, provenance, and cross-observatory synchronization of astronomical objects across time.

1. Introduction

Modern astronomy requires deterministic and reproducible methods for identifying and tracking celestial bodies across observational platforms, simulation pipelines, and temporal baselines. Traditional catalogs encode positional and orbital parameters but lack a universal informational identity that integrates physical observables, entropy, energy scale, temporal indexing, and metadata.

The Quantum Hash Descriptor (QHD) addresses this gap by providing a deterministic mapping from astronomical observables to a continuous descriptor and a cryptographically stable hash. This enables:

- universal object identity
- reproducible kinematic tracking
- provenance-grade metadata integration

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- multi-scale applicability

The Solar System serves only as a minimal example; the framework is intended for universal deployment.

2. Theoretical Framework

2.1 State Representation

Let an astronomical object be denoted by O at time t . Its state representation is:

$$P_0(t) \geq 0, P_0(t) = P_0(t)^\dagger, \text{Tr}(P_0(t)) = 1. \quad (1)$$

2.2 Effective Observable Summary

$$X_0(t) = \text{Tr}(P_0(t) H_{\text{eff}}(t)). \quad (2)$$

2.3 Entropy and Normalized Entropy

$$S(P_0) = -\text{Tr}(P_0 \log P_0). \quad (3)$$

$$S_{\text{norm}} = \frac{S(P_0)}{S_{\text{max}}} \in [0,1]. \quad (4)$$

2.4 Energy Scale

$$E_0 = M_0 c^2, M_0 > 0. \quad (5)$$

2.5 Temporal Indexing

Atomic Time (TAI)

$$T(t) = T_0 + n\Delta t. \quad (6)$$

Proper Time

$$w_O(t) = \tau_O(t). \quad (7)$$

2.6 Causal Descriptor

$$C(t) \in \{0,1\} \text{ or } C(t) \in [0,1]. \quad (8)$$

2.7 Metadata Layer

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Metadata includes:

- object name
- class (planet, star, galaxy, etc.)
- coordinate frame
- units
- protocol version
- observational source

2.8 Continuous Representation

$$\text{Re}(H_{\text{cont}}) = \log_{10}(E_0) + \frac{K}{100} (S_{\text{norm}} - S_{\text{ref}}). \quad (9)$$

$$\text{Im}(H_{\text{cont}}) = \gamma S_{\text{norm}}. \quad (10)$$

$$H_{\text{cont}} = \text{Re}(H_{\text{cont}}) + i \text{Im}(H_{\text{cont}}). \quad (11)$$

2.9 Discrete Hash Representation

$$h_q(O; t) = \text{SHA3-256}(\text{Serialize}(\Xi_O(t))). \quad (12)$$

$$\Xi_O(t) = (H_{\text{cont}}, T(t), C(t), M_O). \quad (13)$$

3. Universal Applicability

The QHD applies to:

- planetary systems
- stellar systems
- exoplanets
- galaxies
- black holes
- nebulae

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- cosmic filaments
- dark-matter halos

The framework scales across **30+ orders of magnitude**, preserving deterministic identity.

4. Solar System Example (Snapshot)

4.1 Reference Frame

Solar System Barycentric (SSB).

4.2 Atomic Time

$$T_{\text{TAI}} = 63,276,546,329 \text{ s.} \quad (14)$$

4.3 Proper Time

Each body has a proper time was defined in the dataset.

4.4 Unified Table

Included in **Annex A**.

5. Kinematic Analysis

Given two snapshots t_1 and t_2 :

$$\vec{v}_o = \frac{\vec{r}_o(t_2) - \vec{r}_o(t_1)}{T(t_2) - T(t_1)}. \quad (15)$$

$$\|\vec{v}_o\| = \sqrt{v_x^2 + v_y^2 + v_z^2}. \quad (16)$$

6. Integration with QHF

6.1 Canonical Tuple

$$\Xi_o(t) = (H_{\text{cont}}, T(t), C(t), M_o). \quad (17)$$

6.2 Serialization

Canonical JSON with sorted keys.

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6.3 Hash Generation

SHA3-256.

6.4 Multi-Snapshot Hash Chains

$$h_q(O; t_1) \rightarrow h_q(O; t_2) \rightarrow h_q(O; t_3) \rightarrow \dots \quad (18)$$

7. Institutional Applications

- Astronomical provenance
- Cross-observatory synchronization
- Simulation reproducibility
- Catalog integrity
- Universal object identity
- Multi-scale indexing

8. References

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2. Borrego Romero, C. D. *Operational Definitions for the Quantum Hash Framework*.
3. Borrego Romero, C. D. *Data-Anchored Quantum Hash Framework*.
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